IMAGE PROCESSING
Chpt-2

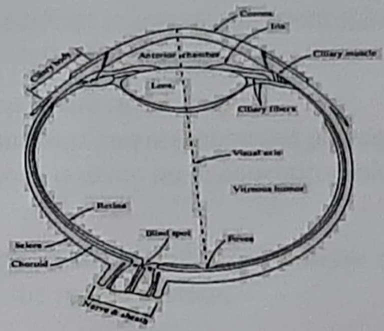
Cornea

- The cornea is a tough, transparent tissue that covers the anterior surface of the eye.
- Continuous with the cornea, the sclera is an opaque membrane that encloses the remainder of the optic globe.

Choroid

- The choroid lies directly below the sclera.
- This membrane contains a network of blood vessels that serve as the major source of nutrition to the eye.
- The choroid coat is heavily pigmented and hence helps to reduce the amount of extraneous light entering into the eye and the backscatter within the optical globe.

Structure of the Human Eye



- The eye is nearly a sphere, with an average diameter of approximately 20mm.
- Three membranes enclose the eye:
- Cornea, sclera outer cover the choroid and the retina.

Retina

- The inner most membrane of the eye is the retina, which lines the inside of the entire posterior portion.

- When the eye is properly focused, light from an object outside the eye is imaged on the retina.

- Pattern vision is afforded by the distribution of discrete light receptors over the surface of the retina.

- The choroid is divided into the ciliary body and the iris diaphragm.

- The latter expands to control the amount of light that enters the eye.

- The front of the iris contains the visible pigment of the eye, whereas the back contains a black pigment.

- Two classes of receptors are: Cones and rods.

- # cones in each eye between 6 and 7 millions.

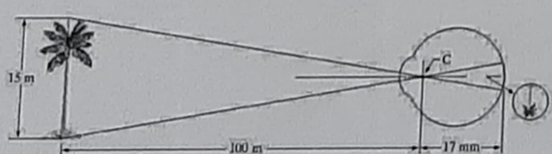
- These are located primarily in the central portion of the retina, called the fovea, and are highly sensitive to color.

- The lens is made up of concentric layers of fibrous cells and is suspended by fibers that attach to the ciliary body.

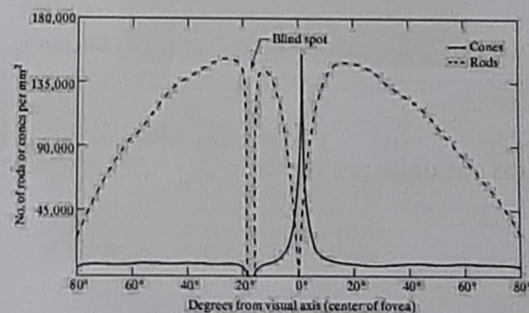
- It contains 60 to70% water, about 6% fat, and more protein than any other tissue in the eye.

- The absence of receptors in this area results in blind spot.
- Cones are the most dense in the center of the retina.
- Muscles, controlling the eye, rotate the eye ball until the image of an object of interest falls on the fovea.
- Cone vision is called photopic or bright-light vision.
- # rods: 75 to 150 million. These are distributed over the retinal surface.

Image Formation in the Eye

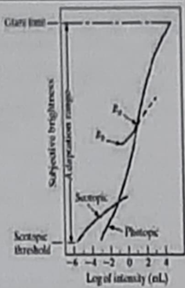


Density of rods and cones for a cross section of the right eye



Human eye can adapt to an enormous range (in the order of 10^{10}) of light intensity levels, from scotopic threshold to the glare limit.

FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.



Subjective brightness (i.e. perceived intensity) is a logarithmic function of the light intensity incident on the eye.

In photopic vision alone, the range is about 10^6 (-2 to 4 in the log scale). The transition from scotopic to photopic vision is gradual over the range (0.001, 0.1) millilambert[1] (-3 to -1 mL in the log scale).[2]

- Incremental illumination ΔI appears in the form of a short duration of flash.

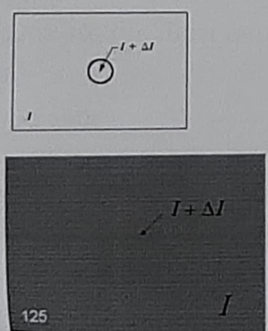
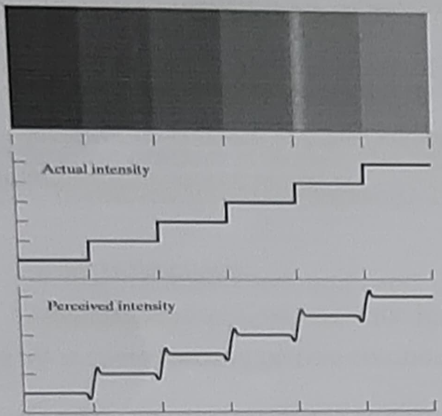


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Note: I is luminance, measured in cd/m^2

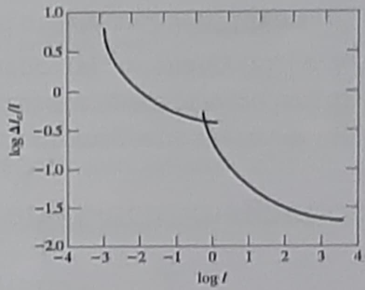
- Focal length: The distance between the center of the lens and the retina.
- It varies from approximately 17mm to about 14mm.
- When the eye focuses on an object farther away the lens exhibits its lowest refractive power.
- When the eye focuses on a nearby object, the lens is most strongly refractive.
- Ex: An observer is looking at a tree 15m height at a distance of 100m.
- 15/100 = h/17 or
- h = 2.55mm.

h = height in mm of that object in the retinal image.

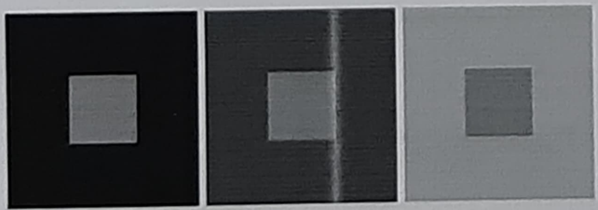


a
b
c

FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.



These appear to the eye to become darker as the background gets lighter.

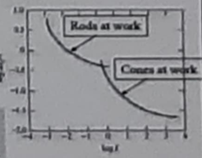


a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

A small Weber ratio indicates "good" brightness where a small percentage change in illumination is discriminable. On the other hand, a large Weber ratio represents "poor" brightness indicating that a large percentage change in intensity is needed.

The curve shows that brightness discrimination is poor (large Weber ratio) at low level of illumination, and it improves significantly (Weber ratio decreases) as background illumination increases.



The two branches illustrate the fact that at low levels of illumination, vision is carried out by the rods, whereas at high levels (showing better discrimination), cones are at work.

A Simple Image Formation Model

- Form of an image: *f(x, y)*, a two dimensional function.

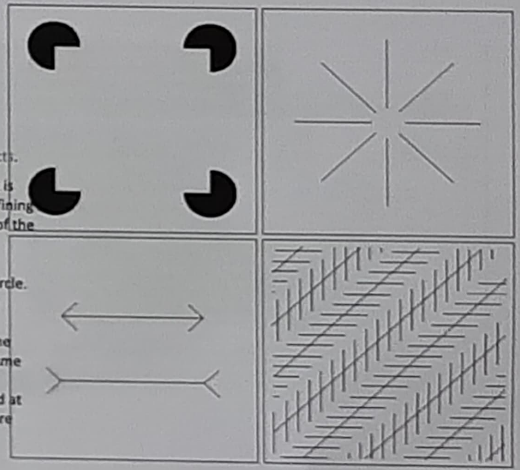
- Value or amplitude of *f* at spatial coordinates (x, y) is intensity value (brightness).

- *f(x, y)* is finite and non zero.

FIGURE 2.9 Some well-known optical illusions.

Eye wrongly perceives geometrical properties of objects.

a. Outline of square is seen (no lines defining a figure are part of the image.
b. Few lines give illustration of a circle.
c. (no lines defines circle)
d. Two horizontal line segments with same length (no).
e. Lines are oriented at 45 degrees and are equidistant and parallel(no).



- f(x, y) is characterized by two components: illumination and reflectance, i*(x, y) and r(x, y), respectively.*

- *The amount of source which is*
  - incident on a scene in being viewed, i(x, y).
  - reflected by objects in a scene, r(x, y).

The metric unit of measure for illuminance of a surface: Lumen per square meter (lm/m^2)

Light and Electromagnetic Spectrum

- The electromagnetic spectrum can be expressed in terms of wave length (λ) , frequency (v) , or energy (e), i.e. $\lambda = c/v$;
- Speed of light c= 2.998*108ms.
- Energy of electromagnetic spectrum E = h v
  h is Plank"s constant, measured in microns (μm) or nanometers (nm).

GRAY SCALE

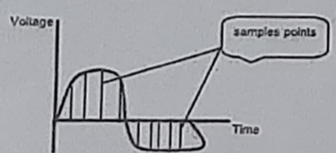
- The interval [Lmin, Lmax] is called the *gray scale.*
- Common practice is to shift this interval numerically to the interval [0, L-1],
- *L=0 is considered black and L=L-1 is considered white on the gray scale.*
- *All intermediate values are shades of gray varying from black to white.*

Some Typical Ranges of Reflectance

- Reflectance
  - 0.01 for black velvet
  - 0.65 for stainless steel
  - 0.80 for flat-white wall paint
  - 0.90 for silver-plated metal
  - 0.93 for snow

Image Sampling and Quantization

- These are needed to convert continuous data into digital form.
- Sampling: Take samples and digitize them on x-axis.
- Ex: y = sin(x), it is done on x variable.



- $f(x, y) = i(x, y)r(x, y)$

  $r(x, y) = 0$--- total absorption

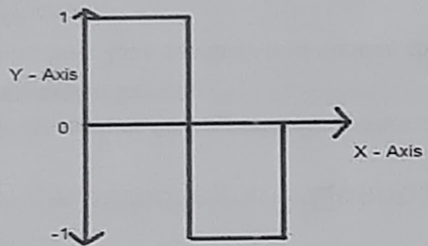
  1 --- total reflection

  $0 < i(x, y) < \infty$,

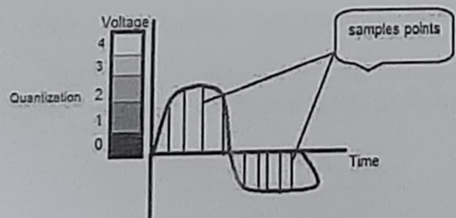
- *Gray level (l) of an image at a point* (x_0, y_0)

  $l = f(x_0, y_0)$.

Digitizing amplitudes:



- The above signal has been quantified into three different levels.



- It is further divided into two parts , up sampling and down sampling.
- There are some random variations in the signal.
- These variations are due to noise.
- In sampling, we reduce this noise by taking samples more.
- if you take sampling on the x axis, the signal is not converted to digital format, unless you take sampling of the y-axis too which is known as quantization.

- Quantization is opposite to sampling. It is done on y-axis.

- When you are quantizing an image, you are actually dividing a signal into quanta ion (partitions).

- On the x axis of the signal (we have co-ordinate values), and on the y axis, we have amplitudes.

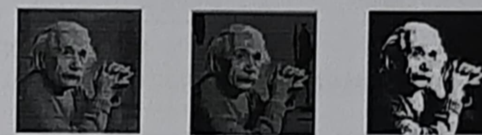
- Digitizing the amplitudes is known as Quantization.

Representing Digital Images

- The representation of an M×N numerical array as

$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Example:



8 gray levels | 4 gray levels | 2 gray levels

Representing Digital Images

- The representation of an M×N numerical array as

$$A=\begin{bmatrix} a_{0,0} & a_{0,1} & \dots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \dots & a_{1,N-1} \\ \dots & \dots & \dots & \dots \\ a_{M-1,0} & a_{M-1,1} & \dots & a_{M-1,N-1} \end{bmatrix}$$

- $L = 2^k$
- Gray level = number of bits per pixel (BPP).(k in the equation).
- Gray level = number of levels per pixel.

Representing Digital Images

TABLE 2.1
Number of storage bits for various values of N and k.

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,360,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Representing Digital Images

- The representation of an M×N numerical array in MATLAB

$$f(x,y)=\begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \dots & \dots & \dots & \dots \\ f(M,1) & f(M,2) & \dots & f(M,N) \end{bmatrix}$$

Spatial and Intensity Resolution

- Spatial resolution
  - A measure of the smallest discernible detail in an image
  - *dots (pixels) per unit distance, dots per inch (dpi)*
- Intensity resolution
  - The smallest discernible change in intensity level
  - stated with *8 bits, 12 bits, 16 bits, etc.*

Representing Digital Images

- Discrete intensity interval [0, L-1], $L=2^k$
- The number b of bits required to store a M × N digitized image

$b = M \times N \times k$

Basic Relationships Between Pixels

- Interpolation— Process of using known data to estimate unknown values.
- Interpolation (*resampling*)—an imaging method to increase (or decrease) the number of pixels in a digital image.

Spatial and Intensity Resolution

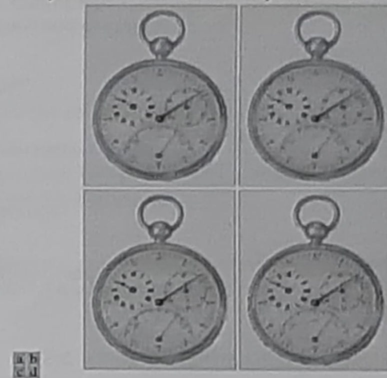


FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

3x3 matrix is interpolated to 6x6 matrix

10	4	22
2	18	7
9	14	25

10	10	4	4	22	22
10	10	4	4	22	22
2	2	18	18	7	7
2	2	18	18	7	7
9	9	14	14	25	25
9	9	14	14	25	25

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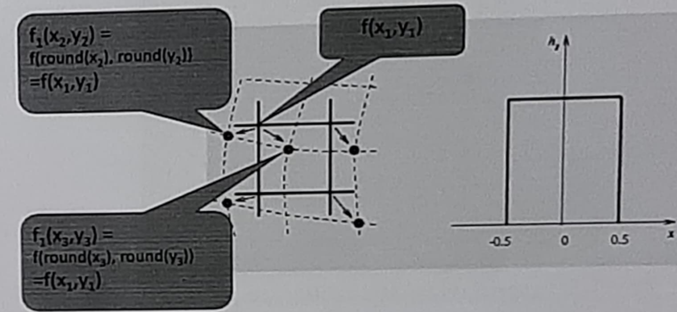
Spatial and Intensity Resolution

FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

- Adjacency is used for **establishing boundaries of objects and components** of regions in an image.
- Two pixels are said to be connected, if they are adjacent in some sense (neighbour pixels,4/8/m-adjacency) or if their gray levels satisfy a specified criterion of similarity(equal intensity level)

Image Interpolation:
Nearest Neighbor Interpolation



Basic Relationships Between Pixels

- Neighbors of a pixel p at coordinates (x,y)

➢ 4-neighbors of p, denoted by $\mathbf{N_4(p)}$:
(x-1, y), (x+1, y), (x,y-1), and (x, y+1).

➢ 4 diagonal neighbors of p, denoted by $\mathbf{N_D(p)}$:
(x-1, y-1), (x+1, y+1), (x+1,y-1), and (x-1, y+1).

➢ 8 neighbors of p, denoted $\mathbf{N_8(p)}$
$N_8(p) = N_4(p) \cup N_D(p)$

Basic Relationships Between Pixels

- Neighborhood
- Adjacency
- Connectivity
- Paths
- Regions and boundaries

Basic Relationships Between Pixels

- **Path:**

➢ A (digital) path (or curve) from pixel p with coordinates (x_0, y_0) to pixel q with coordinates (x_n, y_n) is a sequence of distinct pixels with coordinates

$(x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n)$

where (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 \leq i \leq n$.

➢ Here *n* is the *length* of the path.

➢ If $(x_0, y_0) = (x_n, y_n)$, the path is ***closed*** path.

➢ We can define 4-, 8-, and m-paths based on the type of adjacency used.

Basic Relationships Between Pixels

- Adjacency

Let V be the set of intensity values

➢ 4-adjacency: Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.

➢ 8-adjacency: Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$.

Examples: Adjacency and Path

V = {1, 2}

0	1	1		0	1	1		0	1	1
0	2	0		0	2	0		0	2	0
0	0	1		0	0	1		0	0	1

Basic Relationships Between Pixels

- **Adjacency**

Let V be the set of intensity values

➢ m-adjacency: Two pixels p and q with values from V are m-adjaceny if

(i) q is in the set $N_4(p)$, or

(ii) q is in the set $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels whose values are from V.

Examples: Adjacency and Path

V = {1, 2}

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix}$$

8-adjacent **m-adjacent**

The 8-path from (1,3) to (3,3):
(i) (1,3), (1,2), (2,2), (3,3)
(ii) (1,3), (2,2), (3,3)

The m-path from (1,3) to (3,3):
(1,3), (1,2), (2,2), (3,3)

Examples: Adjacency and Path

V = {1, 2}

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix}$$

8-adjacent

Connectivity

- For any pixel p in S, the set of pixels in S that are connected to p, is a connected component of S.
- If S has only one connected component, then S is called a connected set.
- Region
- R is a region in an image if R is a connected set
- Two regions, R_i and R_j are adjacent if their union forms a connected set.

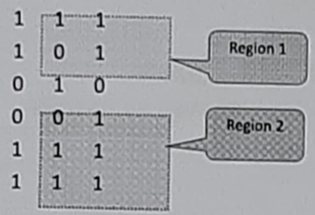
Examples: Adjacency and Path

V = {1, 2}

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix}$$

8-adjacent **m-adjacent**

- **In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)**

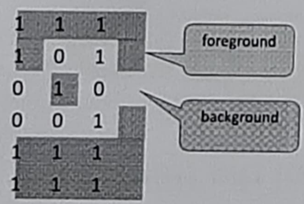


- **Regions that are not adjacent are disjoint.**
- Region adjacency **is defined with respect to** both 4-adjacency **and** 8-adjacency.

Boundary:

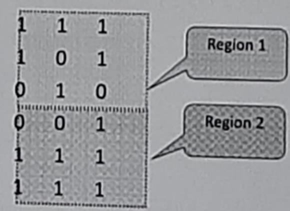
A boundary is defined in terms of 4- or 8-adjacency.

- **In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)**



Question 1

- **In the following arrangement of pixels, are the two regions (of 1s) adjacent? (if 8-adjacency is used)**



Distance measures

- Euclidean distance between *p* and *q*:

- *De(p,q)* = [(*x-s*)2 + (*y-t*)2]1/2
- *D4* distance (also called *city-block distance*):
- *D4(p,q)* = |*x-s*| + |*y-t*|
- *D8* distance (also called *chessboard distance*) :
- *D8(p,q)* = max (|*x-s*| , |*y-t*|)

$D_e(p,q) = \sqrt{(x-s)^2+(y-t)^2}$